High Performance, Low-Cost III-V Concentrator Module

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ABSTRACT

This paper describes the objectives and scope of the work to be carried out by Spectrolab under the High Performance PV Initiative (HiPer PV) of NREL. The work scope involves development of a low-cost, high-efficiency terrestrial solar cell and a receiver module design.

Introduction

Due to their high costs, III-V photovoltaic cells must be used in a concentrator system to enable commercially feasible terrestrial power generation, with sufficiently low $/watt. In a concentrator system, ultra-high efficiency solar cells enable greater electric power generation capacity for a given concentrator size, thus reducing the cost per watt of all system components from the cell, to the concentrating collector, to the support structures and other balance-of-system costs. The higher the concentration ratio becomes, the less the solar cell cost becomes as part of the overall system cost. The major hurdle in achieving high concentration, however, is the thermal and thermo-mechanical issues associated with high solar flux and high temperature. PV receivers must be designed to enable efficient thermal management of the solar cells, while utilizing compatible materials and processes to lower the thermal expansion mismatch stresses.

The contract between Spectrolab and NREL under the HiPer PV initiative aims at addressing the challenges associated with both ultra-high efficiency cells and receiver designs. The duration of the contract is two years. As the contract has just started, this paper will focus more on the objectives and scope of the work to be performed, and less on specific results.

Objectives

The goal of this contract is to develop a low-cost, high-efficiency concentrator cell and module. Specific objectives are:

1. Design and fabricate high-efficiency (30-35%), high-reliability concentrator cells;
2. Demonstrate new ultra-high-efficiency (capable of 35-40% efficiency) concentrator cell approaches;
3. Reduce the cost of manufacturing solar cells, particularly Ge substrate cost;
4. Deliver 100 concentrator solar cells for Entech;
5. Design and fabricate a reliable receiver package that has an efficient thermal management capability.

Work Scope

This section gives more details on the previously mentioned objectives. It highlights why and how each objective is going to be carried out.

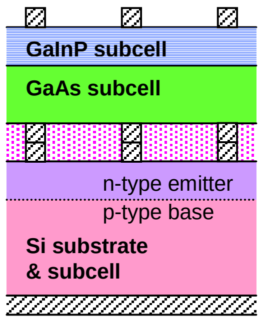
<u>High-Efficiency, High-Reliability 3J Solar Cells</u>

This work will develop near-term improvements to monolithic 3-junction (3J) GaInP/GaAs/Ge concentrator cells [1-3], to increase their efficiency and robustness under high concentraton levels. Cell structures that have been shown to yield higher photogenerated current density and voltage in 3J solar cells for space will be adapted to the different spectra and incident intensity conditions for terrestrial concentrator cell operation. Concentrator cells handle very large currents and current densities, requiring contact resistance to be in the 10^{-4}-10^{-3} range, and preferably lower. Further, the presence of any metal path in the semiconductor can cause the cell to be shunted, leading to the loss of a significant portion of the module output power. Robust solar cell metallization structures can eliminate the need for 100% cell shunting tests. Spectrolab is conducting a set of experiments with different metallization structures to determine the best scheme to use from both aspects of (i) robustness to shunting effects, and (ii) contact resistance.

<u>Ultra-High Efficiency Solar Cell</u>

The goal of this area of research is to extend the efficiency of multijunction (MJ) concentrator cells above the present record efficiencies of 34% for Spectrolab triple-junction cells [4] (NREL confirmed, AM1.5G, 130-630 suns, 25°C), potentially to efficiencies approaching 40%.

This work will explore novel monolithic cell designs such as metamorphic 3-junction GaInP/GaInAs/Ge cells and 4-junction GaInP/GaAs/GaInNAs/Ge cells. This research will also demonstrate very-high efficiency MJ cell approaches that require longer term development but are capable of efficiencies approaching 40%, that integrate cells from more than one type of substrate, such as 3-junction GaInP/GaAs/Si concentrator cells.



<u>Fig. 1.</u> Schematic diagram of a 3-junction cell composed of a GaInP/GaAs 2-junction cell integrated with a silicon solar cell.

<u>Low Cost Terrestrial Solar Cell</u>

A typical cost split for III-V solar cells is one-third wafer cost, one-third epitaxial growth, and one-third cell fabrication. Epitaxial growth and cell fabrication are amenable to cost reductions through manufacturing improvements and increased volume, but reducing the portion due to wafer cost while retaining high-efficiency requires a focused research collaboration between solar cell manufacturers and wafer vendors.

<u>Delivery of 100 Concentrator Cells for Entech</u>

Entech is under contract with NREL under the same HiPer PV initiative to demonstrate a near-term 440-sun module using fresnel lenses. Entech is interested in using Spectrolab's high efficiency III-V cells for their module. Pending successful demonstration of new metallization structures, Spectrolab will fabricate and test 100 cells and deliver them to Entech. The major issue with the Entech module from the cell perspective comes from the fact that the cell will be subject to a highly non-uniform illumination. The impact of this on the performance and long-term reliability of solar cells will be studied.

<u>Receiver Design</u>

The PV receiver design plays a key role in determining the maximum concentration level than can be supported and hence the overall $/W of any given system. The key challenge in designing a receiver is the material selection tradeoff involving thermal dissipation ability (i.e. thermal conductivity), compatibility (i.e. coefficient of thermal expansion, CTE), and cost. Most metals, for example, are good thermal conductors but their CTE is much higher than that of germanium or silicon. The large expansion mismatch could result in failure of solder connections between the cell and the heat sink, if soldered directly to each other. If we were to use thermal adhesives to bond the cell to the heat sink to absorb the large expansion mismatch between the two, the cell temperature goes up. By using composites of high thermal conductivity and matched CTE, e.g. aluminum nitride, the cost of the receiver goes up.

Another issue associated with the receiver design is making the electrical connections between the cells. It is important to select an interconnection method that is reliable and can be easily automated for cost reduction. The interconnection method must allow for either series or parallel connection, and be such that if a cell is lost (due to shunting or for whatever reason), a minimal loss of output power occurs.

Project Status

Development of highly robust metallization structures for concentrator solar cells have been an area of intense focus in the early stages of the program. Currently 4 main groups of cells have been fabricated, with one group having standard metallization, and the other three implementing a diffusion barrier between the metal and the semiconductor to eliminate cell shunting.

References

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